Resuscitation 82 (2011) 1235–1238

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Short communication

Feasibility of pulse oximetry in the initial prehospital management of victims of drowning: A preliminary study[☆]

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ARTICLE INFO

Article history:
Received 12 February 2011
Received in revised form 30 March 2011
Accepted 21 April 2011

Keywords:
Drowning
Oxygen
Pulse oximetry

ABSTRACT

Aim: Immediate delivery of oxygen is the most important treatment for victims of drowning at the rescue site. Monitoring oxygen saturation with pulse oximetry is potentially useful, but its use may be limited by poor peripheral perfusion due to hypothermia. This preliminary study explores the feasibility of pulse oximetry in simulated minor drowning scenarios.
Materials and methods: Six different pulse oximeters were tested on ten healthy volunteers after brief submersion, after ten minutes of swimming in a swimming pool (warm water, temperature 21 °C), and in the sea (cold water, temperature 16 °C). A measured oxygen saturation reading ≤94% was assumed to be incorrect.
Results: There was considerable variability between each pulse oximeter. In warm water, 5.8% of measurements were outside the predicted range (8.3% after submersion, 3.3% after swimming), compared to 34% in cold water (20% after submersion, 48% after swimming). The spurious measurements came from two pulse oximeters in warm water, but from all six in cold water. The best and worst performing pulse oximeters showed 5% and 33% measurements respectively outside the predicted range.
Conclusion: The performance of pulse oximeters varies considerably in healthy volunteers submersed or immersed in warm or cold water. Further studies are needed to understand these differences.

1. Introduction

Drowning remains a common cause of accidental death.[1–3] Many victims of drowning suffer from hypoxia, which should be treated with oxygen as soon as possible.[4–6] Delivery of oxygen by lifeguards is therefore becoming a popular on beaches, in swimming pools and on rescue boats.[7,8] Pulse oximetry is potentially useful in this setting to detect hypoxaemia, to monitor the effects of oxygen therapy, and to avoid the possible adverse effects of hyperoxia.[7,9,10] Poor peripheral perfusion can make pulse oximeter readings inaccurate.[11–14] In drowning victims, hypothermia causes poor peripheral perfusion and therefore the value of pulse oximeters in drowning victims is unknown. This preliminary study assesses the ability of different pulse oximeters to measure oxygen saturation in healthy volunteers after brief submersion or 10 min immersion, in warm and cold water.

2. Methods

2.1. Pulse oximeters

Thirteen medical equipment distributors were invited to provide pulse oximeters free of charge. Four distributors provided six portable pulse oximeters: Nonin Onyx and PalmSat (Nonin Medical Inc., Plymouth, USA), Nellcor N-65 (Covidien-Nellcor, Boulder, USA), GE TuffSat (GE Healthcare, Waukesha, USA), PM-60 (Mindray Medical, Nanshan, China), and LifePak 20 (Medtronic, Minneapolis, USA).

2.2. Subjects

Ten volunteer lifeguards meeting the following criteria were recruited from local services: male, age 18–40 years, with a recent health assessment certificate, ASA I, not extremely dark or pale skinned, and a non-smoker. All participants gave written informed

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at doi:10.1016/j.resuscitation.2011.04.019.

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doi:10.1016/j.resuscitation.2011.04.019

consent. The study was approved by the VU University Medical Centre ethics board.

2.3. Baseline characteristics and measurements

The body mass index (BMI) of volunteers was determined by measuring the height and weight. The second, third and fourth fingers (digits II–IV) of both hands were used to measure oxygen saturation with all 6 pulse oximeters simultaneously. To rule out bias caused by differences between the volunteers or pulse oximeters, oxygen saturation was measured with all 6 pulse oximeters on the second finger (digit II) of the right hand in all volunteers under normal circumstances (at rest, in normal clothing at room temperature). In addition, oxygen saturation was measured on digits II–IV of both hands with each pulse oximeter to rule out differences between the fingers. Blood pressure was also measured on both arms to rule out perfusion differences.

2.4. Setting and test situations

The pulse oximeters were tested at two locations in the city of Vlissingen, the Netherlands, on the same day. The first location was a covered swimming pool with warm water (water temperature 21 °C, air temperature 25 °C). The second location was a sea harbour with relatively cold water (water temperature 16 °C, air temperature 19 °C). There was a two-h scheduled break between the swimming pool and sea tests. The pulse oximeters were fitted with new batteries after the pool tests. At both locations there were two sets of tests. In the first test, each volunteer jumped in the water, taking care to be completely submerged, turned around immediately and rested both hands on a soft surface out of the water. In the second test, the volunteer swam at low speed for ten minutes, and then put both hands on the surface. Whilst the volunteer floated relaxed in the water, both hands were dried off. The six pulse oximeters were then simultaneously, and in a standardized procedure, attached to digits II–IV of both hands, and the oxygen saturation readings were recorded when a stable reading was achieved.

2.5. Safety measures

Lifeguards often enter swimming pools and seas under circumstances similar to those in our study. Despite this, safety measures were taken. Anesthesiologists, EMS-paramedics and additional lifeguards were present. Standard EMS equipment was available in the swimming pool and in the harbour. During the tests in the harbour a rescue boat was present.

2.6. Data analysis

Previous studies show that baseline oxygen saturation measurements during immersion, non-strenuous swimming or exercise are between 95% and 100% in healthy individuals.[15,16] Based on these findings, we have assumed that the oxygen saturation in our volunteers will not fall below 95%. An oxygen saturation ≤94% was therefore considered to be less than the predicted arterial oxygen saturation. The number of pulse oximetry measurements ≤94% for each pulse oximeter per test was determined. In addition, the variation in readings between the pulse oximeters was assessed. Baseline data have been checked for normal distribution by Kolomogorov–Smirnov test. Further analysis of the results is descriptive.

Table 1
Baseline characteristics and measurements.

Characteristics	Mean (SD)
Age (years)	22.1 (3.2)
BMI (kg m^{-2})	22.6 (1.6)
Blood pressure, right arm (mm Hg)	123/69 (10.6/8.4)
Blood pressure, left arm (mm Hg)	124/70 (8.4/8.4)

3. Results

3.1. Baseline characteristics and measurements

The mean values and standard deviations of age, body mass index (BMI) and blood pressure measurements of the ten volunteers are presented in Table 1. The measured baseline oxygen saturation under normal conditions was 96–100% in all volunteers, except for two measurements of 94% by the Nonin PalmSat. No volunteer had differences between digits II–IV of both hands.

3.2. Test situations

Fig. 1 shows all oxygen saturation measurements in the different test situations, with the 94% measured oxygen saturation cut off point. Measurements of 70% or lower are shown as ≤70%. In warm water of 21 °C, 5/60 (8.3%) of measurements were less than predicted after brief submersion, compared to 2/60 (3.3%) after 10 min swimming. In cold water of 16 °C, 12/60 (20%) and 29/60 (48%) respectively were less than predicted. Over all test situations, the LifePak 20 performed the best with only 2/40 (5%) spurious measurements and the Nonin PalmSat the worst with 13/40 (33%) spurious measurements.

There was a large disparity in readings outside the predicted range. After swimming in cold water, the Nellcor N-65 did not display any value in 7 volunteers, depicted as “7 no readings” on the ≤70% line (Fig. 1). All of the other oxygen saturation values obtained with this pulse oximeter in cold water swimming were 100%. The other pulse oximeters also gave less than predicted oxygen saturations with cold water swimming: the Lifepak 20 between 64% and 78%; the PM-60 between 36% and 93%; the Nonin Onyx between 54% and 94%; the GE TuffSat between 80% and 90%; and the Nonin PalmSat between 80% and 93%.

4. Discussion

In this preliminary study, pulse oximetry did not reliably measure oxygen saturations in healthy individuals after brief submersion and after swimming in either warm or cold water. In relatively warm swimming pool water, four pulse oximeters did not fail, but in outdoor cold water all pulse oximeters failed. There was also considerable variability between different pulse oximeters. In actual drowning scenarios, with a lower water temperature, or prolonged time in the water, or a non-healthy victim, pulse oximetry measurements may be even more inaccurate. Software, intensity of the light source or fitting of the finger clips may be responsible for this.

Oxygen is a key early treatment for the resuscitation of drowning victims.[7] The detection of hypoxaemia and monitoring of oxygen therapy may however be difficult. The routine administration of 100% inspired oxygen is potentially harmful during resuscitation of drowning victims if hyperoxia occurs.[7,9,10] Over the last few decades, professional and volunteer lifeguards and rescue boat crews have been increasingly equipped with oxygen delivery devices. Studies related to extremes in aquatic sports and diving physiology have used pulse oximetry successfully to obtain data on arterial oxygen saturation.[15–18] These studies show that,

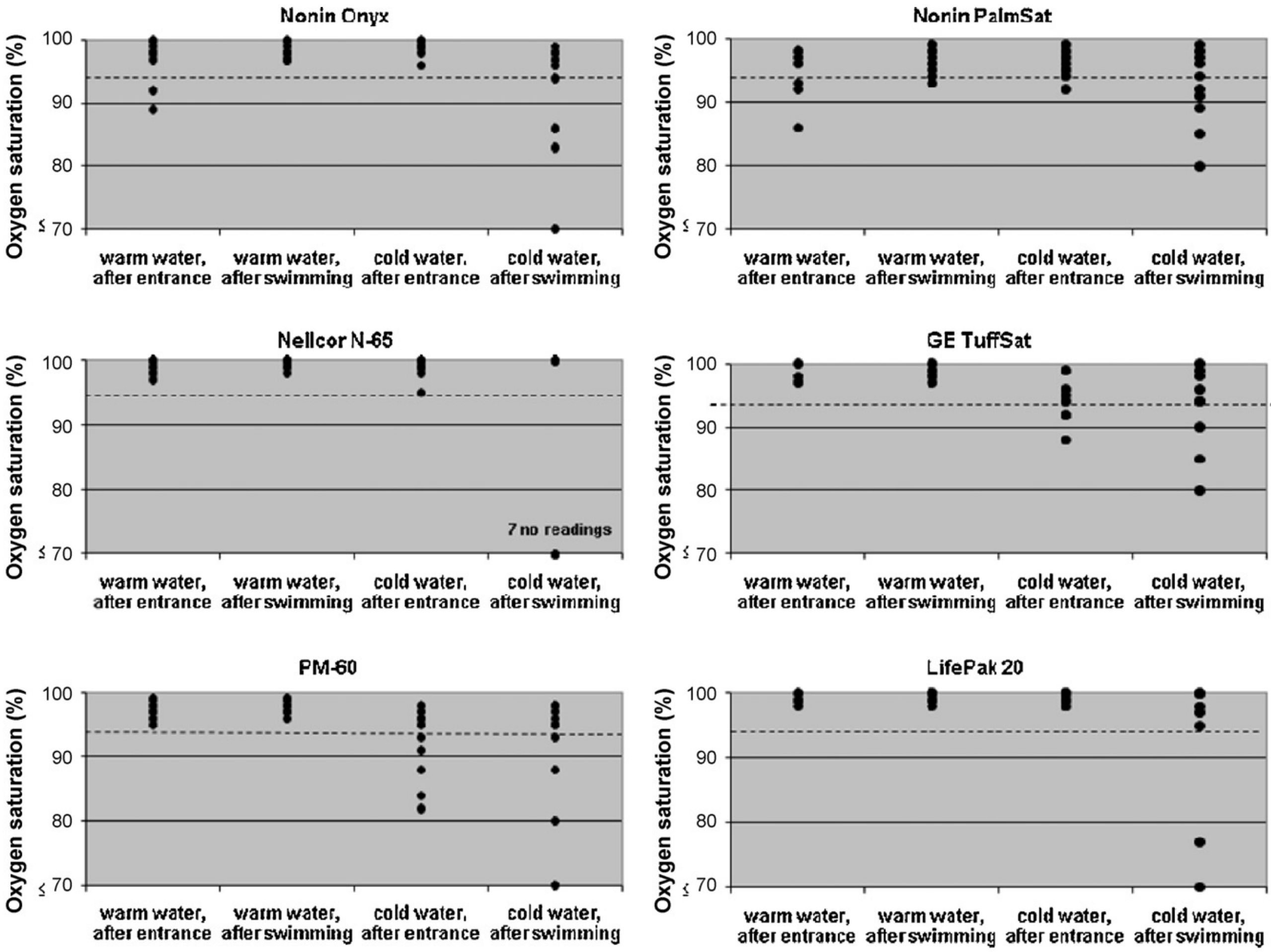

Fig. 1. Line plots for all pulse oximeters, showing all oxygen saturation values (*y*-axis) per test situation (*x*-axis), with 94% cut off value of spurious measurements. Measurements of 70% or less are gathered in "≤70".

when well prepared, pulse oximetry can be applied in the aquatic environment. Our study in more common drowning situations suggests that pulse oximeters should not be routinely used to measure oxygen saturation in this setting during initial resuscitation.

Our study has several limitations. First of all, we did not measure the actual arterial oxygen saturation from an arterial blood sample using co-oximetry. We assumed any pulse oximetry reading of ≤94% was inaccurate as the oxygen saturation of our study participants was very likely to remain above 94%. Studies dealing with sports training and exercise in water confirm this.[15,16] The technical and ethical issues involved to undertake blood sampling and measurement were beyond the scope of this preliminary study. Moreover, the aim of the present study was to explore whether a more complex study is needed. During the experiments, there was a large amount of variability between the pulse oximeters. This variability confirms the conclusion that pulse oximeters are not yet suitable for use in the initial resuscitation of drowning victims. Another limitation is that number of pulse oximeters, volunteers, and measurements was small. The test situations were realistic, and similar to circumstances that are present during actual drowning rescues. The resources present in this setting were limited. A more artificial study design could have led to more robust data, but this was not the aim of this real-life study.

The intention of this preliminary study was to obtain information and experience whether using pulse oximetry in drowning would be worthwhile and feasible. Our tests do not provide the full answer. Our results suggest that currently available pulse oximeters have no added value for the initial diagnosis and treatment of hypoxia in drowning victims.

5. Conclusion

The performance of pulse oximeters varies considerably in healthy volunteers submersed or immersed in warm or cold water. Further studies are needed to understand these differences.

Conflict of interests

The authors are not related to, or financially supported by the pulse oximeter manufacturers. The manufacturers have not been involved in the design, analysis, or writing of the manuscript, and were aware that the results of the study were intended for publication. This study was funded by the City of Vlissingen and the Dutch Association for Swimming-pools and Swimming-certificates (NPZ|NRZ).

Acknowledgements

The authors thank all volunteers (lifeguards, EMS personnel and staff members from the City of Vlissingen and NPZ|NRZ) who participated in this study, especially Albert Dijkstra and Anton Mekkering, who did all essential coordination and planning. The authors also like to thank the manufacturers and distributors who were willing to provide the pulse oximeters.

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